Philosophy of quantum mechanics

VU University Amsterdam: W_MASP_TF013 Lecture 5: 17/2/2015
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Today's lecture

- Essay questions.
- Recap of measurement problem (from lecture 1).
  - Formalism relevant for more precise formulation.
    - Linearity of the dynamics.
    - Collapse postulate.
- Albert's formulation of the measurement problem.
  - Based on a specific measurement situation (1992 ch. 4).
  - Why it's hard to study collapse experimentally (1992 ch. 5).
- Maudlin's formulation of the measurement problem.
  - More general formulation based on inconsistent triad.
  - Enables us to define possible solutions.
- Solutions and principles of theory selection.

Short essays are due in ten days!

Philosophical categories	Essay questions
Philosophy of science	(i) Does quantum mechanics introduce novel reasons for accepting scientific anti-realism? (ii) What is the dimensionality of space according to (non-relativistic) quantum mechanics? 3 or 3ND?
Philosophy of mind	(i) Is there any reason to think that the mind-body problem and the measurement problem are connected? (ii) What are the implications of quantum mechanics for the causal closure argument for physicalism?
Metaphysics	(i) What are the implications of quantum mechanics for atomism? (ii) What are the implications of quantum mechanics for intrinsicality?

Philosophy of science (i)

- Does quantum mechanics introduce novel reasons for accepting scientific anti-realism?

- Reading:
  - Wallace (see lecture 1 folder)

- Does the idea of superposition motivate Bohr-style anti-realism (Copenhagen interpretation)?
- Does the textbook's appeal to measurement motivate instrumentalism?
- Are David Wallace's arguments for realism sound?

Philosophy of science (ii)

- What is the dimensionality of space according to (non-relativistic quantum mechanics)? 3D or 3ND?

- Reading
  - Ney (see lecture 3 folder).

- Why do Ney and others believe that entanglement cannot be understood in 3 spatial dimensions?
- Are they correct?
- If so, can we make sense of why we experience a 3D world?

Philosophy of mind (i)

- Is there any reason to think that the mind-body problem and the measurement problem are connected?

- Reading:
  - Chalmers (see lecture 2 folder).
    - Hard problem is defined here. See lecture 2 slides for other issues.

- If textbook quantum mechanics treats 'measurement' as a fundamental process, does this suggest a challenge to physicalism?
- Does the hard problem of consciousness provide motivation for interpreting 'measurement' as meaning 'conscious observation'?
- Does quantum mechanics have implications for the free will debate?

Philosophy of mind (ii)

- What are the implications of quantum mechanics for the causal closure argument for physicalism?

- Reading:
  - See Papineau (and Dennett) quotes in lecture 2 slides.

- Does the textbook's appeal to 'measurement' undermine the physicalist's appeal to causal closure?
- What is the quantum closure principle and is Papineau justified in believing it?

Metaphysics (i)

- (i) What are the implications of quantum mechanics for atomism?

- Reading:
  - Esfeld (see lecture 4 folder).

- Does quantum mechanics refute sophisticated forms of atomism like Humean Supervenience?
- Is there a form of atomism that can account for (global) entanglement?
- Which of the views on slide 45 of lecture 4 is the most plausible ontology?

Metaphysics (ii)

- (ii) What are the implications of quantum mechanics for intrinsicality?

- Reading:
  - McQueen and van Woudenberg (see lecture 4 folder).

- Does quantum mechanics cause problems for the definition of 'intrinsic property'?
- Are there any intrinsic properties if quantum mechanics is true?
- If not, does realising this advance our knowledge of the structure of reality?

Essay writing

- Please pick two essay questions. They must be from distinct philosophical categories.
  - These are not research essays.
    - I've only mentioned one reading for each.
  - They offer you a chance to start writing clearly about quantum mechanics and its impact on philosophy.
  - You will receive detailed written feedback.
- Due 27 Feb. Upload to blackboard by midnight.
  - Along with math exercises and definition of measurement problem (see assessment handout).

- The final essay (due 27 March) is a research essay that must engage the philosophy of quantum mechanics literature.

Recap (measurement problem)

Recap

- Definition of measurement problem from lecture 1:
  - Quantum mechanics postulates two laws, a deterministic and an indeterministic law. Presumably they cannot both apply at once, but the standard view only states that one but not the other applies during measurement.

- Now that we've covered the relevant aspects of the mathematical formalism, we can state the problem more clearly.
  - The most crucial tools will be:
    - Linearity of the dynamics.
    - The collapse postulate.

Linearity of the dynamics

- Suppose system S is subject to certain specific forces and constraints.
- And suppose the dynamics entails that given those forces and constraints:
  - **If S’s initial state is |A> then S’s later state is |A’>**
- And:
  - **If S’s initial state is |B> then S’s later state is |B’>**

- Then *the linearity* of the dynamics entails that given those same forces and constraints:
  - **If S’s initial state is #|A>+ #|B> then S’s later state is #|A’>+ #|B’>.**

Linearity of the dynamics (2-path exp.)

- Suppose electron e is subject to the 2-path experiment.
- And suppose the dynamics entails that given these forces and constraints:
  - **If e's initial state is: |hard>|x1,y1> then e's later state is: |hard>|h-path>**
- And:
  - **If e's initial state is: |soft>|x1,y1> then e's later state is: |soft>|s-path>**

- Then *the linearity* of the dynamics entails that given those same forces and constraints:
  - **If e's initial state is:**
    #|hard>|x1,y1> + #|soft>|x1,y1>
    then e's later state is:
    #|hard>|h-path> + #|soft>|s-path> .

Collapse

- Measurement of the property represented by operator O when the measured system is not in an eigenstate of O will collapse the system into such an eigenstate, with a certain probability.
  - The probability is calculated using Born's Rule:
    - The probability of finding a particle in state |A> to be in state |B> is calculated by multiplying the vectors and squaring the result.
      - (Squaring the *modulus* of the result for complex coefficients.)
  - If |A> is written in the basis of the operator we are measuring for, then we can just read the probabilities off that state vector.
  - So a *colour* measurement on: $|gleb+1> = \frac{1}{2}|black> + \frac{\sqrt{3}}{2}|white>$

  ...will yield white with 0.75 probability.

Albert's "The Measurement Problem"

The measurement problem

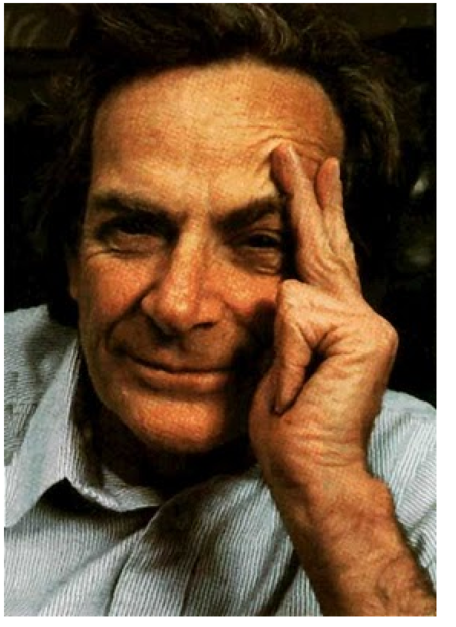
- Lecture 1 definition:
  - Quantum mechanics postulates two laws, a deterministic and an indeterministic law. ***Presumably they cannot both apply at once***, but the standard view only states that one but not the other applies during measurement.

- Why exactly can't they apply at once? Why aren't they just two different ways of getting the same result?

- Let's be more precise about the inconsistency using the formalism, by asking what happens to measuring devices according to the dynamics.
  - This is important as the measurement problem is often misunderstood...

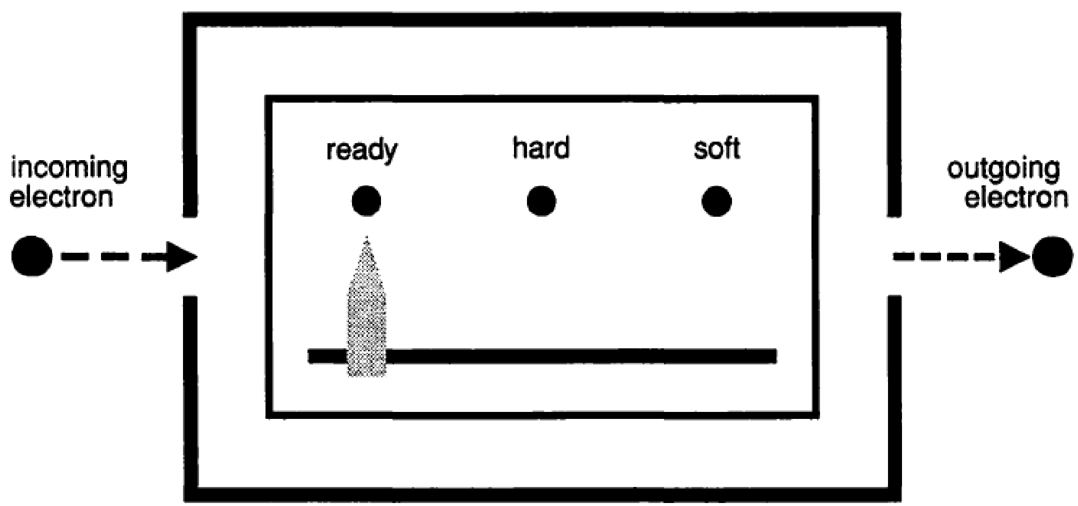
Defining the measurement problem

- "[We] always have had (secret, secret, close the doors!) we always have had a great deal of difficulty in understanding the world view that quantum mechanics represents. You know how it always is, every new idea, it takes a generation or two until it becomes obvious that there is no real problem. It has not yet become obvious to me that there's no real problem. I cannot define the real problem, therefore I suspect there's no real problem, but I'm not sure there's no real problem."
  - Richard Feynman In "Simulating Physics with Computers" 1982, p471.



The set-up

- Suppose the dynamics is universal.
  - Everything evolves according to the Schrödinger equation, including measuring devices.
- Suppose we construct a hardness box that indicates the measurement result with a pointer:



The measuring device dynamics

- The pointer points to "ready" until we insert an electron, then the pointer moves depending on the hardness state of the electron.
- In other words:

$$|\text{"}ready\text{"}>_m |hard>_e \rightarrow |\text{"}hard\text{"}>_m |hard>_e$$

$$|\text{"}ready\text{"}>_m |soft>_e \rightarrow |\text{"}soft\text{"}>_m |soft>_e$$

- Subscripts *m* and e designate respective states of the measuring device and electron.
- The arrows indicate how the joint pointer-electron states evolve if the electron is inserted into the device.

The measuring device dynamics

- For a black electron, the pre-measurement state is:

$$|"ready" >_m |black >_e$$

- Which can be rewritten as the separable state:

$$= |"ready" >_m \left(\frac{1}{\sqrt{2}}|hard >_e + \frac{1}{\sqrt{2}}|soft >_e\right)$$

$$= \frac{1}{\sqrt{2}}|"ready" >_m |hard >_e + \frac{1}{\sqrt{2}}|"ready" >_m |soft >_e$$

Linearity

- If the pre-measurement state is:

$$\frac{1}{\sqrt{2}}|"ready" >_m |hard >_e + \frac{1}{\sqrt{2}}|"ready" >_m |soft >_e$$

- Then what must the post-measurement state be? Recall linearity:
  - If we know that:

$$|A > \longrightarrow |A' >$$
$$|B > \longrightarrow |B' >$$

  - Then linearity guarantees that:

$$\#|A > + \#|B > \longrightarrow \#|A' > + \#|B' >$$

- Now let's work it out...

Linearity

- If we know that:

$$|\text{"}ready\text{"}>_m |hard>_e \rightarrow |\text{"}hard\text{"}>_m |hard>_e$$

$$|\text{"}ready\text{"}>_m |soft>_e \rightarrow |\text{"}soft\text{"}>_m |soft>_e$$

- Then linearity guarantees that:

$$\frac{1}{\sqrt{2}}|\text{"}ready\text{"}>_m |hard>_e + \frac{1}{\sqrt{2}}|\text{"}ready\text{"}>_m |soft>_e$$

$$\rightarrow \frac{1}{\sqrt{2}}|\text{"}hard\text{"}>_m |hard>_e + \frac{1}{\sqrt{2}}|\text{"}soft\text{"}>_m |soft>_e$$

Linearity

- So from physical facts about the measuring device and the linearity of the dynamics we can infer that if the pre-measurement state is the separable one:

$$|\text{"}ready\text{"} >_m \left(\frac{1}{\sqrt{2}}|hard >_e + \frac{1}{\sqrt{2}}|soft >_e\right)$$

$$= \frac{1}{\sqrt{2}}|\text{"}ready\text{"} >_m |hard >_e + \frac{1}{\sqrt{2}}|\text{"}ready\text{"} >_m |soft >_e$$

- Then the post-measurement state is the nonseparable one:

$$\frac{1}{\sqrt{2}}|\text{"}hard\text{"} >_m |hard >_e + \frac{1}{\sqrt{2}}|\text{"}soft\text{"} >_m |soft >_e$$

Conflicting results

- Now that we know that the dynamics guarantees the post-measurement result...

$$\frac{1}{\sqrt{2}}|"hard">_m |hard>_e + \frac{1}{\sqrt{2}}|"soft">_m |soft>_e$$

- ...we can compare this with what the collapse postulate guarantees:
  - Either of the following two:

$$|"hard">_m |hard>_e$$
$$|"soft">_m |soft>_e$$

  - With 0.5 probability for each.
- These are measurably different states!

A “somewhat sharper” formulation

- Still no *definitive* conflict yet…
  - Perhaps we applied the collapse postulate too early in the measurement process?
- Then let the dynamics run further…
  - Martha is a competent observer of measurement device pointers. From which it follows:

$$|'ready' >_o |"ready" >_m \rightarrow \; |'ready' >_o |"ready" >_m$$

$$|'ready' >_o |"soft" >_m \rightarrow \; |'soft' >_o |"soft" >_m$$

$$|'ready' >_o |"hard" >_m \rightarrow \; |'hard' >_o |"hard" >_m$$

  - Where $|'ready' >_o$ refers to a state of the observer’s brain: Martha’s belief that the device reads “ready”.

A “somewhat sharper” formulation

- The competence of Martha as an observer, together with the linearity of the dynamics, entails that when Martha observes the pointer reading, the overall state will be:

$$\frac{1}{\sqrt{2}}|'hard'>_o |"hard">_m |hard>_e + \frac{1}{\sqrt{2}}|'soft'>_o |"soft">_m |soft>_e$$

- Since the collapse postulate gives different results (i.e. collapse to either the first or second term with 0.5 probability) we again have conflicting results.
- Based on Martha’s own subjective experience, *the collapse postulate is right* while the dynamics is “bizarrely wrong”.

What is it like to be in a superposition?

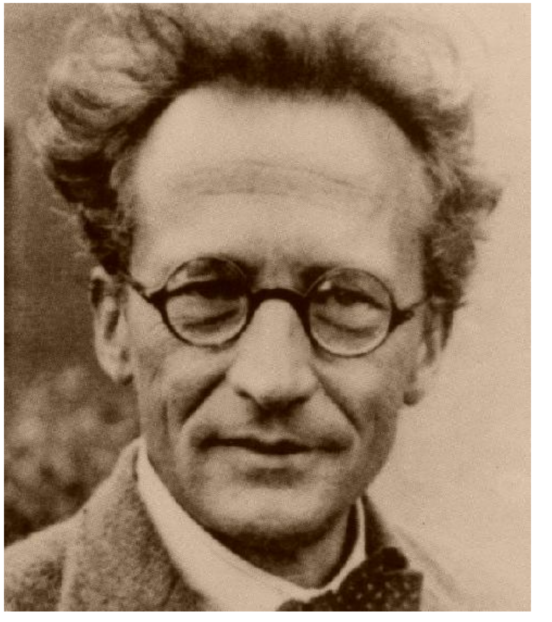
- Being in this state:

$$\frac{1}{\sqrt{2}}|'hard'>_o|"hard">_m|hard>_e+\frac{1}{\sqrt{2}}|'soft'>_o|"soft">_m|soft>_e$$

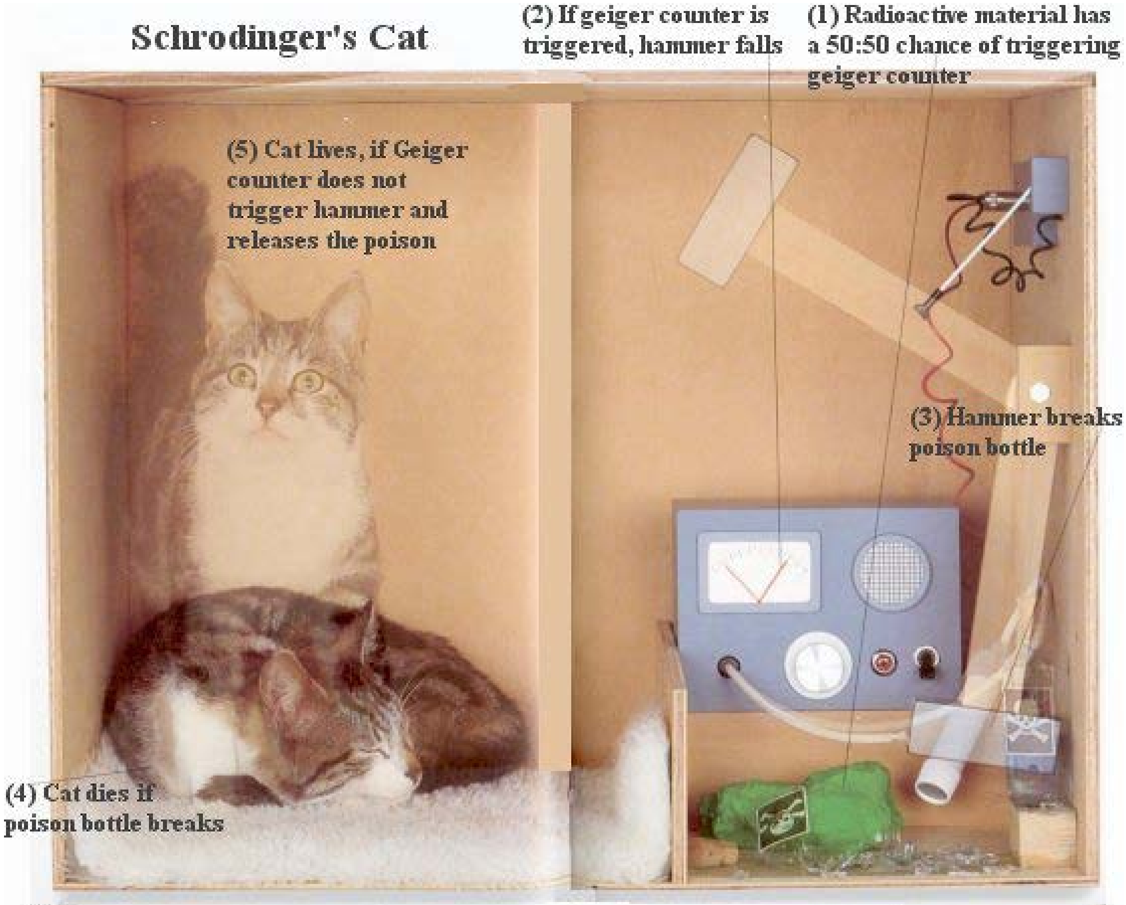
- Is being in a very strange state:
  - On Bohr's view: Martha doesn't believe the device reads "hard", nor "soft" nor both nor neither.
  - But she's not merely confused about it!
  - Since we (apparently) don't experience being in such states when performing measurements they (presumably) don't occur.
- So the dynamics and the collapse postulate *inevitably* contradict, this is the problem.

Schrödinger's cat

- "One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, so small, that perhaps in the course of the hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The psi-function of the entire system would express this by having in it the living and dead cat (pardon the expression) mixed or smeared out in equal parts."
  - Erwin Schrödinger In *The Present Situation in Quantum Mechanics* (1935).



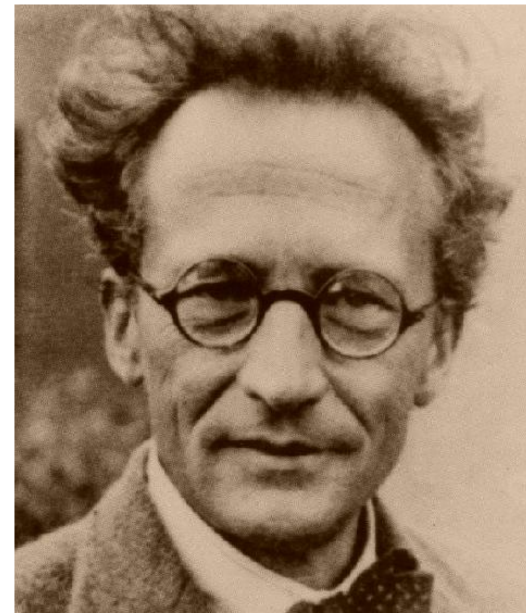
Schrödinger's cat



Homework exercise: write up the state vectors for this scenario. Consider the role of the linearity of the dynamics.

Schrödinger's solution?

- "It is typical of these cases that an indeterminacy originally restricted to the atomic domain becomes transformed into macroscopic indeterminacy, which can then be resolved by direct observation. That prevents us from so naively accepting as valid a 'blurred model' for representing reality. In itself it would not embody anything unclear or contradictory. There is a difference between a shaky or out-of-focus photograph and a snapshot of clouds and fog banks."
  - Erwin Schrödinger In *The Present Situation in Quantum Mechanics* (1935).



Wigner's solution

- "The paradox of Wigner's friend" refers to Physicist Eugene Wigner's follow-up thought experiment.
  - In Wigner's "Remarks on the Mind-Body Problem" (1967).
    - Lecture 5 folder.
- Wigner asks his friend to perform the experiment and determine the cat's fate, and then leaves.
- Wigner returns, to ask his friend about the result...
- If Wigner's friend is part of the linearly evolving system then Wigner's friend evolves into a superposition of distinct beliefs (like Martha).
- On this basis Wigner argues that it is only superpositions of *consciousness* that make no sense, so it must be consciousness (either the cat's or the friend's) that collapses the system.
  - First statement of the consciousness causes collapse theory.

Other (vague) suggestions

- Is collapse triggered by conscious measurement?
  - Albert worries that "conscious" is also too imprecise.
    - We will return to this in later lectures.
- Is collapse triggered by being big?
  - Same problem: how big is "big"?
- Vague terms are not helpful in general.
  - They admit "admissible precisifications".
    - Different precisifications then generate different physical theories.
  - They admit "borderline cases".
    - When borderline cases obtain it will be indeterminate what law obtains
- So whatever the collapse mechanism is, it must be *precisely* specifiable.

Experimentally testing for collapse

Testing collapse hypotheses

- The collapse of the wave-function is a physical event.
- So it should have detectable consequences.
- So we should be able to determine by experiment when and where collapse occurs (if at all).

- How to perform such experiments?
  - Consider different collapse hypotheses regarding a hardness measurement of a black electron…

Two collapse hypotheses

- Device hypothesis: measuring device causes collapse:

$$t1: |'ready' >_o |"ready" >_m \left(\frac{1}{\sqrt{2}}|hard >_e + \frac{1}{\sqrt{2}}|soft >_e\right)$$

$$t2: |'ready' >_o |"hard" >_m |hard >_e \text{ with } 0.5 \text{ probability OR}$$

$$|'ready' >_o |"soft" >_m |soft >_e \text{ with } 0.5 \text{ probability}$$

- Brain hypothesis: observer's brain causes collapse:

$$t1: |'ready' >_o |"ready" >_m \left(\frac{1}{\sqrt{2}}|hard >_e + \frac{1}{\sqrt{2}}|soft >_e\right)$$

$$t2: |'ready' >_o \left(\frac{1}{\sqrt{2}}|"hard" >_m |hard >_e + \frac{1}{\sqrt{2}}|"soft" >_m |soft >_e\right)$$

$$t3: |'hard' >_o |"hard" >_m |hard >_e \text{ with } 0.5 \text{ probability OR}$$

$$|'soft' >_o |"soft" >_m |soft >_e \text{ with } 0.5 \text{ probability}$$

Two collapse hypotheses

- The device and brain hypotheses disagree about the quantum state at time t2:
  - Device hypothesis:

$$t2\text{: } |'ready'>_o |"hard">_m |hard>_e \ with\ 0.5\ probability\ OR$$
$$|'ready'>_o |"soft">_m |soft>_e \ with\ 0.5\ probability$$

  - Brain hypothesis:

$$t2\text{: } |'ready'>_o \left(\frac{1}{\sqrt{2}}|"hard">_m |hard>_e + \frac{1}{\sqrt{2}}|"soft">_m |soft>_e\right)$$

- So we just need to test who is right about the t2 state.

Device hypothesis Vs brain hypothesis

- The hypotheses about the t2 states:

$$t2: |'ready' >_o |"hard" >_m |hard >_e \text{ with } 0.5 \text{ probability OR}$$

$$|'ready' >_o |"soft" >_m |soft >_e \text{ with } 0.5 \text{ probability}$$

$$t2: |'ready' >_o \left(\frac{1}{\sqrt{2}}|"hard" >_m |hard >_e + \frac{1}{\sqrt{2}}|"soft" >_m |soft >_e\right)$$

- ...disagree about:
  - The position of the pointer.
    - Device hypothesis says it's definite.
    - Brain hypothesis says it isn't.
  - The hardness of the electron.
    - Device says it's definite.
    - Brain hypothesis says it isn't.

Device hypothesis pointer measurement

- **What does the device hypothesis predict for a pointer position measurement?**

  - According to the device hypothesis, since the state at t2 is:

$$t2\text{: } |'ready' >_o |"hard" >_m |hard >_e \text{ with } 0.5 \text{ probability } OR$$

$$|'ready' >_o |"soft" >_m |soft >_e \text{ with } 0.5 \text{ probability}$$

  - ...then a measurement of the pointer position will find the pointer's state to be:

$$|"hard" >_m \text{ with } 0.5 \text{ probability } OR$$

$$|"soft" >_m \text{ with } 0.5 \text{ probability}$$

Brain hypothesis pointer measurement

- **What does the brain hypothesis predict for a pointer position measurement?**

  - According to the brain hypothesis, since the state at t2 is:

$$t2\colon |'ready'>_o \left(\frac{1}{\sqrt{2}}|"hard">_m |hard>_e + \frac{1}{\sqrt{2}}|"soft">_m |soft>_e\right)$$

  - ...then a measurement of the pointer position will **collapse the pointer's state and then** find it to be:

$$|"hard">_m \ with\ 0.5\ probability\ OR$$

$$|"soft">_m \ with\ 0.5\ probability$$

Device hypothesis Vs brain hypothesis

- Same results!
  - Pointer position measurements cannot determine who is right about the t2 state.

- The hypotheses also disagree about the hardness of the electron, so let's look at their predictions about hardness measurements on the electron…

Device hypothesis electron masurement

- What does the device hypothesis predict for an electron hardness measurement?

  - According to the device hypothesis, since the state at t2 is:

$$t2: |'ready' >_o |"hard" >_m |hard >_e \; with\; 0.5\; probability\; OR$$
$$|'ready' >_o |"soft" >_m |soft >_e \; with\; 0.5\; probability$$

  - ...then a measurement of the electron hardness will find the electron's state to be:

$$|hard >_e \; with\; 0.5\; probability\; OR$$
$$|soft >_e \; with\; 0.5\; probability$$

Brain hypothesis electron measurement

- **What does the brain hypothesis predict for an electron hardness measurement?**

  - According to the brain hypothesis, since the state at t2 is:

$$t2{:}\ |'ready' >_o \left(\frac{1}{\sqrt{2}}|"hard" >_m |hard >_e + \frac{1}{\sqrt{2}}|"soft" >_m |soft >_e\right)$$

  - ...then a measurement of the electron hardness will **collapse the electron's state and then** find it to be:

$$|hard >_e \ with\ 0.5\ probability\ OR$$

$$|soft >_e \ with\ 0.5\ probability$$

Device hypothesis Vs brain hypothesis

- Same results again!
  - Electron hardness measurements cannot determine who is right about the t2 state.
  - Nor can electron colour or gleb or scrad (etc.) measurements.
    - Substitute the equations and see (cf. EPR argument).

- What's going wrong?
  - According to the brain hypothesis, neither the pointer nor the electron has any definite states, at t2.
  - So measurements of the pointer or the electron will collapse them into the states that the device hypothesis predicts they are already in.
- This suggests what the *right* experiments are...

The only experiments that will work

- We need to find a way to measure a state like this:

$$t2\text{:}\ \frac{1}{\sqrt{2}}|\text{"}hard\text{"}>_m |hard>_e + \frac{1}{\sqrt{2}}|\text{"}soft\text{"}>_m |soft>_e$$

- ...without collapsing it.

- So we need to:
  - Work out what operator this state is an eigenstate of.
  - Work out what property that operator represents.
  - Find a way of measuring that property.
    - If the composite system is in that eigenstate, then the device hypothesis is false, and the brain hypothesis is corroborated.

Why such experiments are difficult

- Imagine we finally work out that this state:

$$t2\text{:}\ \frac{1}{\sqrt{2}}|\text{"}hard\text{"} >_m |hard >_e + \frac{1}{\sqrt{2}}|\text{"}soft\text{"} >_m |soft >_e$$

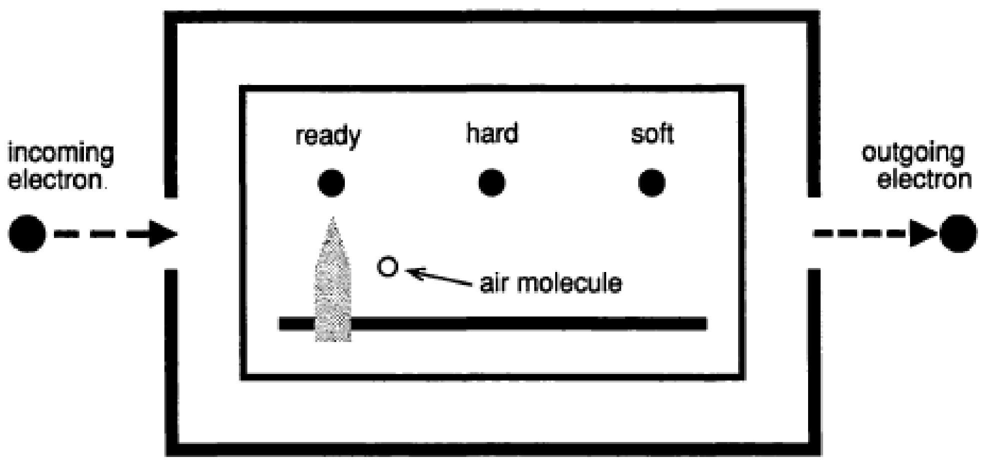
- …is an eigenstate of operator O, which represents property P.
- We now want to measure the t2 state for property P.
- Unfortunately this is nearly impossible.
  - We would have to prevent the m+e composite system from entangling with its environment.
  - That requires that we completely isolate m+e from its environment.
  - We may never have the technology to actually do this!

Why such experiments are so difficult

- To illustrate: imagine we try but let in an air molecule "a", that sits near the left side of the device, and to the right of the pointer.
  - Then the t1 state is:

$$t1\text{: } |'ready'>_o |left>_a |"ready">_m \left(\frac{1}{\sqrt{2}}|hard>_e + \frac{1}{\sqrt{2}}|soft>_e\right)$$

  - ...or more vividly:



Why such experiments are so difficult

- In that case, our efforts to find a way to measure this state:

$$t2: \frac{1}{\sqrt{2}}|\text{"}hard\text{"}>_m |hard>_e + \frac{1}{\sqrt{2}}|\text{"}soft\text{"}>_m |soft>_e$$

- ... for property P, was all in vain because the more realistic state:

$$t2: \frac{1}{\sqrt{2}}|centre>_a |\text{"}hard\text{"}>_m |hard>_e + \frac{1}{\sqrt{2}}|right>_a |\text{"}soft\text{"}>_m |soft>_e$$

- ...has no definite value for property P.
- The P-measurement will collapse the t2 state (on either theory).

Environment induced entanglement

- So we need to determine what operator this state:

$$t2: \frac{1}{\sqrt{2}}|centre>_a |"hard">_m |hard>_e + \frac{1}{\sqrt{2}}|right>_a |"soft">_m |soft>_e$$

- ...is an eigenstate of, so we can measure the property that operator represents.

- But even if we could do that, realistically there will be other air molecules around, dust particles, photons etc. etc.

- So direct experiment won't (in practice) help us decide between competing collapse hypotheses.

How to evaluate collapse hypotheses?

- Direct experiment is not the only way we can evaluate theories.
- We can ask whether such theories can actually be precisely formulated at all.
  - "Device" causes collapse and "brain" causes collapse are not precisely formulated.
- Once we've achieved the desired precision we can ask whether the theory:
  - is internally coherent;
  - fits with everything else we know about the world;
  - explains what it was supposed to explain;
  - explains what it was supposed to explain better than competing (e.g. no-collapse) theories.
    - i.e. do philosophy!

Still, there *is* experimental research…

- In 2010, Aaron O'Connell received the *Breakthrough of the Year* award for being the first person to superpose an *observable object* and to keep it superposed (for a few nanoseconds).
  - In 2011 he publically presented his research:
    - https://www.ted.com/talks/aaron_o_connell_making_sense_of_a_visible_quantum_object?language=en#t-5946

- There are also experiments at Leiden University attempting to superpose small mirrors.
  - Uses fridges that bring the mirrors to 0.0000003 degrees above absolute zero (-273 degrees Celsius), before firing superposed photons at them.
    - Marshall, W., Simon, C., Penrose, R., Bouwmeester, D. 2003. Towards Quantum Superpositions of a Mirror. *Phys. Rev. Lett.* 91(13) 130401.

Maudlin's "Three Measurement Problems"

Maudlin's three measurement problems:

- **The problem of outcomes** is a more general version of Albert's, based on an inconsistent triad of propositions.
  - This formulation enables Maudlin to:
    - Show that a number of proposed "solutions" miss the point.
    - Categorise plausible solutions in terms of what proposition they reject.
  - Also defined in my Four Tails Problem article (lecture 9 folder).
- **The problem of statistics** is then a refinement which purports to show that the Many Worlds solution misses the point.
  - While it is generally agreed that Maudlin is right about the other proposed solutions, his claim about Many Worlds is controversial.
- **The problem of effect** is a further refinement intended to rule out "modal interpretations".
  - As these are (mostly) no longer advocated (and are arguably refuted in Albert's appendix) I will focus on the first two problems.

The problem of outcomes

- The following three claims are mutually inconsistent.
  - 1.A. The wave-function of a system is complete i.e. the wave-function specifies (directly or indirectly) all of the physical properties of a system.
  - 1.B. The wave-function always evolves in accord with a linear dynamical equation (e.g. the Schrödinger equation).
  - 1.C. Measurements always (or at least usually) have determinate outcomes, i.e., at the end of the measurement the device indicates a definite physical state.

Illustrating the inconsistency

- Albert has essentially illustrated the inconsistency with a concrete example.
  - (1.A.) Imagine the complete wave function is:

$$\frac{1}{\sqrt{2}}|\text{"}ready\text{"}>_m |hard>_e + \frac{1}{\sqrt{2}}|\text{"}ready\text{"}>_m |soft>_e$$

  - (1.B) Then given the linearity of the dynamics inserting electron e into device m yields:

$$\frac{1}{\sqrt{2}}|\text{"}hard\text{"}>_m |hard>_e + \frac{1}{\sqrt{2}}|\text{"}soft\text{"}>_m |soft>_e$$

  - (1.C.) But this is not a determinate outcome such as:

$$|\text{"}soft\text{"}>_m |soft>_e$$

No determinate outcome

- This state vector…

$$\frac{1}{\sqrt{2}}|\text{"}hard\text{"}>_m\ |hard>_e + \frac{1}{\sqrt{2}}|\text{"}soft\text{"}>_m\ |soft>_e$$

- …cannot possibly describe a measuring device in the "hard" but not "soft" state or in the "soft" but not "hard" state due to *symmetry*.
  - The two states enter symmetrically into this state vector.
    - E.g. The state vector does not attribute different properties to either state that one could use to privilege one or the other state.

- Hence if 1.A. and 1.B. are true then 1.C. is false.

Solving the measurement problem

- Since we can formulate the measurement problem as an inconsistent triad of propositions, we can categorise solutions in terms of what proposition they reject.

- This allows us to see:
  - How constrained the possible set of solutions are.
  - What each solution must achieve to actually solve the problem.

The options

- Three options:
  - Deny 1.A. – wave function is incomplete.
  - Deny 1.B. – dynamics is not (always) linear.
  - Deny 1.C. – measurements don't have determinate outcomes.
    - (In principle one could deny more than one!)
- What each involves:
  - Denying 1.A. involves specifying the additional ontology and what laws govern that ontology.
  - Denying 1.B. involves specifying exactly when and how the dynamics fails to be linear.
    - Both introduce *new physics*.
  - Denying 1.C simply involves *making sense* of denying 1.C.

Farewell Copenhagen

- The Copenhagen interpretation denies 1.B.
  - Bohr and others explicitly rejected EPR's argument that QM is incomplete (thus asserting 1.A.).
  - They also insisted that measuring devices be described in classical terms (thus asserting 1.C.).
- But the Copenhagen interpretation *fails* to specify exactly when and how the dynamics stops being linear.
  - "The traditional theory papered over this defect by describing collapses in terms of imprecise notions such as "observation" or "measurement". This is not much better than saying that the evolution is linear except when it is cloudy, and saying no more about how many, or what kind, of clouds precipitate this radical shift in the operation of fundamental physical law." (Maudlin, p9.)

Taxonomy of solutions

- Deny 1.A. – wave function is incomplete.
  - Additional variables theories
    - Bohmian mechanics.
- Deny 1.B. – dynamics is not (always) linear.
  - Collapse theories
    - Triggered collapse theories (e.g. CCC).
    - Spontaneous collapse theories (e.g. GRW).
- Deny 1.C. – measurements don't have single outcomes.
  - Everett interpretation (many-worlds theory)

"Sharpening the problem"

- The three propositions are not *logically* inconsistent.
  - This is why we needed to appeal to symmetry considerations.
  - Consider an implausible but logically possible view that denies that symmetric superpositions ever happen, and argues that the "outcome" of a non-symmetric superposition is given by the more heavily weighted component.

- Let's now move to the problem of statistics, which involves three logically inconsistent propositions and (according to Maudlin) enables us to locate a fatal problem for the Many Worlds theory.

The problem of statistics

- The following three claims are mutually inconsistent.
  - 2.A. The wave-function of a system is complete i.e. the wave-function specifies (directly or indirectly) all of the physical properties of a system.
  - 2.B. The wave-function always evolves in accord with a ***deterministic*** dynamical equation (e.g. the Schrödinger equation).
  - 2.C. ***Measurement situations described by identical initial wave-functions sometimes have different outcomes, the probability of each is given by Born's rule***.

The problem of statistics

- The logical inconsistency:

- If the wave-function always evolves deterministically (2.B) then two systems which begin with identical wave-functions will end with identical wave-functions.
- But if the wave-function is complete (2.A), then systems with identical wave-functions are identical in all respects.
- In particular, they cannot contain detectors which are indicating different outcomes, *contra* 2.C.

Taxonomy of solutions (again)

- Deny 2.A. – wave function is *in*complete.
  - Additional variables theories

- Deny 2.B. – dynamics is *not* (always) deterministic.
  - Collapse theories
    - Identical initial wave-functions evolve (nondeterministically) into distinct wave-functions, explaining their distinct measurement outcomes.

- Deny 2.C. – identical initial wave-functions *don't* have different outcomes. Probabilities are (nonetheless) given by the Born rule.
  - Everett interpretation / many worlds

Farewell Everettians?

- "To deny 2.C is to deny the empirical heart of the theory. This is the deep reason for the unsatisfactory nature of the Many-Worlds approach. For even if we can understand the denial of 1.C, even if we could comprehend how a simple spin measurement could have many results, still no sense could be made of Born's rule. Born's rule gives the probability for a spin measurement to come out "UP" rather than "DOWN". If all such measurements have both results, then there is no probability at all for such an outcome." (Maudlin, 1995, p11)

Illustration of Maudlin's objection

- The pre-measurement state is:

$$|"ready">_m \left(\frac{1}{\sqrt{2}}|hard>_e + \frac{1}{\sqrt{2}}|soft>_e\right)$$

- According to Many Worlds, the linearity of the dynamics entails that the microscopic superposition bifurcates the measuring device, giving *both possible* outcomes:

$$\frac{1}{\sqrt{2}}|"hard">_m |hard>_e + \frac{1}{\sqrt{2}}|"soft">_m |soft>_e$$

- But if we know both outcomes will occur, then surely they occur with probability 1 rather than 0.5?

Illustration of Maudlin's obection

- Debate between David Albert (collapse), Sean Carroll (many-worlds), Sheldon Goldstein (additional variables), and Ruediger Shack (anti-realist).
  - http://www.worldsciencefestival.com/2014/06/measure-measure-can-reconcile-waves-particles-quantum-mechanics/
- Debate between Sean Carroll (many-worlds) and David Albert (critic).
  - http://bloggingheads.tv/videos/1728

A traditional response

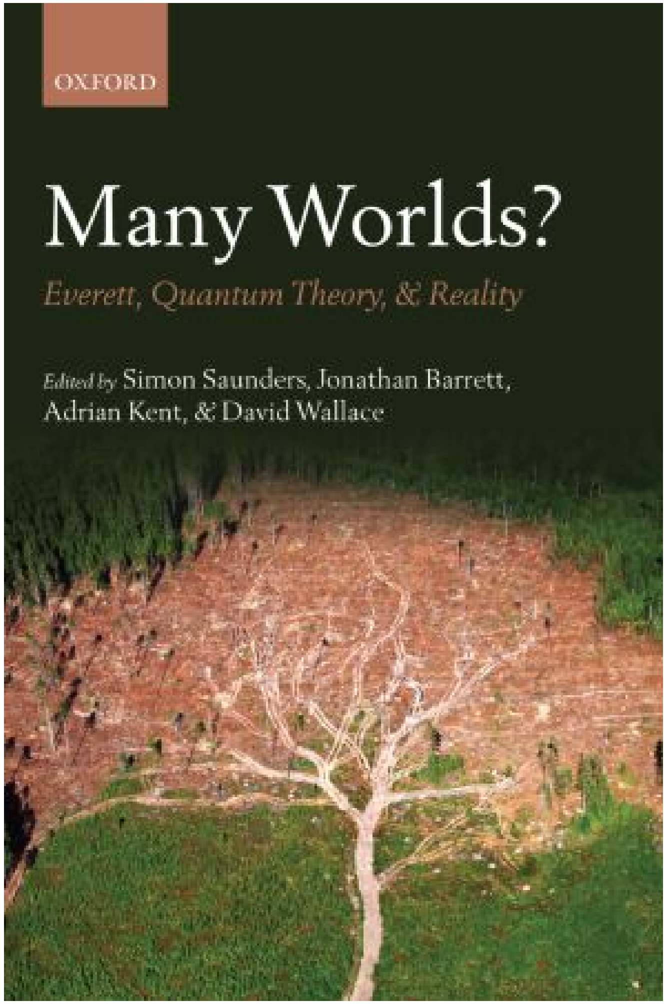
- Imagine an infinite sequence of (say) colour measurements on electrons that are not in colour eigenstates.
- At each measurement the world bifurcates and every possible sequence of results appears on some "branch" of the multiverse.
- Now take the branches where the observed long-term frequency of results matches Born rule predictions.
  - (E.g. If we're always measuring hard electrons find the branches where half the time you get white.)
- In each case the number assigned by Born's rule to those branches approaches 1.
  - Maudlin: this is beside the point since all the branches "happen" with certainty they should all be assigned the same probability, which is in conflict with Born's rule.

A Modern Oxford Everettian response

- "This is simply another of the mistakes imposed on us by orthodox metaphysics. Just as orthodoxy is wrong to suppose that only one of the possible outcomes will occur in a chancy situation, so it is wrong to suppose that the ascription of a non-unitary probability to some outcome is incompatible with knowing for sure that it will occur."
  - David Papineau, In *A Fair Deal for Everettians* (2010 p207).

Many Worlds?

- Whether many-worlds theory can make sense of chance is a lively current debate.
  - Many believe that if many-worlds theory can account for chance, the game is over: we live in a multiverse.
- The current debate is nicely captured in "Many Worlds?" (2010).
  - Essays 6-12 concern probability in many-worlds theory, 6-9 are defences, 10-12 are critiques.
  - Presentations are all online.
    - Everett at 50 conference.
- A potential essay topic!



The Oxford view

- See also David Wallace's (2012) "The Emergent Multiverse".
- This is undoubtedly the most thorough defence of the many worlds interpretation available.
- Chapter 2 is the reading for Thursday.
  - See lecture 6 folder.